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(54) **INTEGRATED E-MACHINE CONTROLLER FOR TURBOMACHINE HAVING FASTENING ARRANGEMENT**

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F02B 39/10	(2006.01)
H02B 1/26	(2006.01)
H02G 5/00	(2006.01)
H02K 9/22	(2006.01)

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CPC ***H02K 5/225*** (2013.01); ***H02K 3/50*** (2013.01); ***H02K 11/30*** (2016.01); *F02B 37/12* (2013.01); *F02B 39/10* (2013.01); *H02B 1/26* (2013.01); *H02G 5/00* (2013.01); *H02K 9/227* (2021.01); *H02K 2203/09* (2013.01)

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USPC .... 310/71, 68 R

See application file for complete search history.

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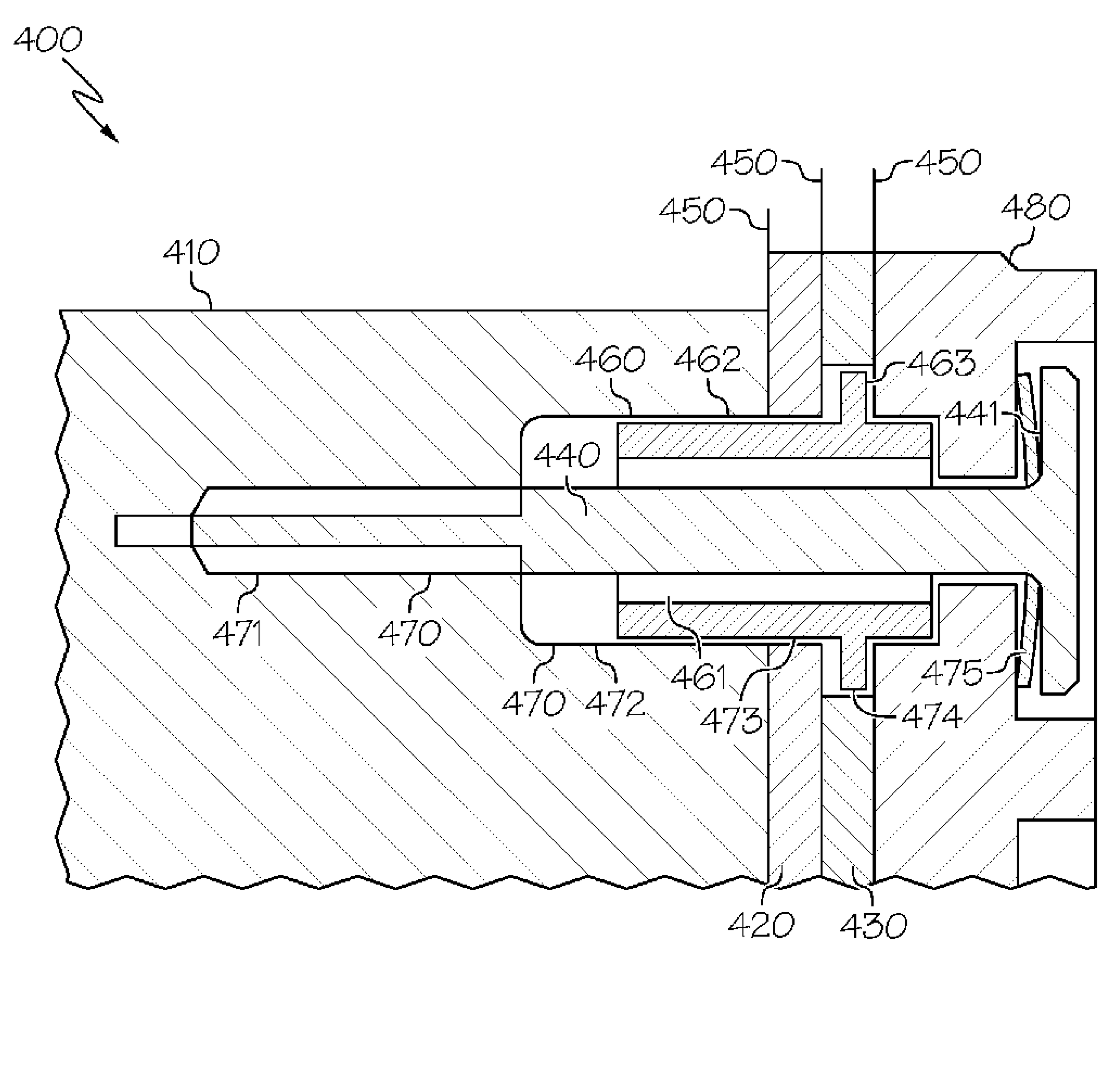
(57) **ABSTRACT**

A fluid compressor device includes a housing and a rotating group supported for rotation within the housing about an axis. The device also includes a controller for an e-machine of a turbomachine having a rotating group that is supported for rotation about an axis including a support structure, a first bus bar that is elongate and that extends about the axis, a second bus bar that is elongate and that extends about the axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis, and a fastener arrangement that attaches the first bus bar and the second bus bar to the support structure.

18 Claims, 4 Drawing Sheets



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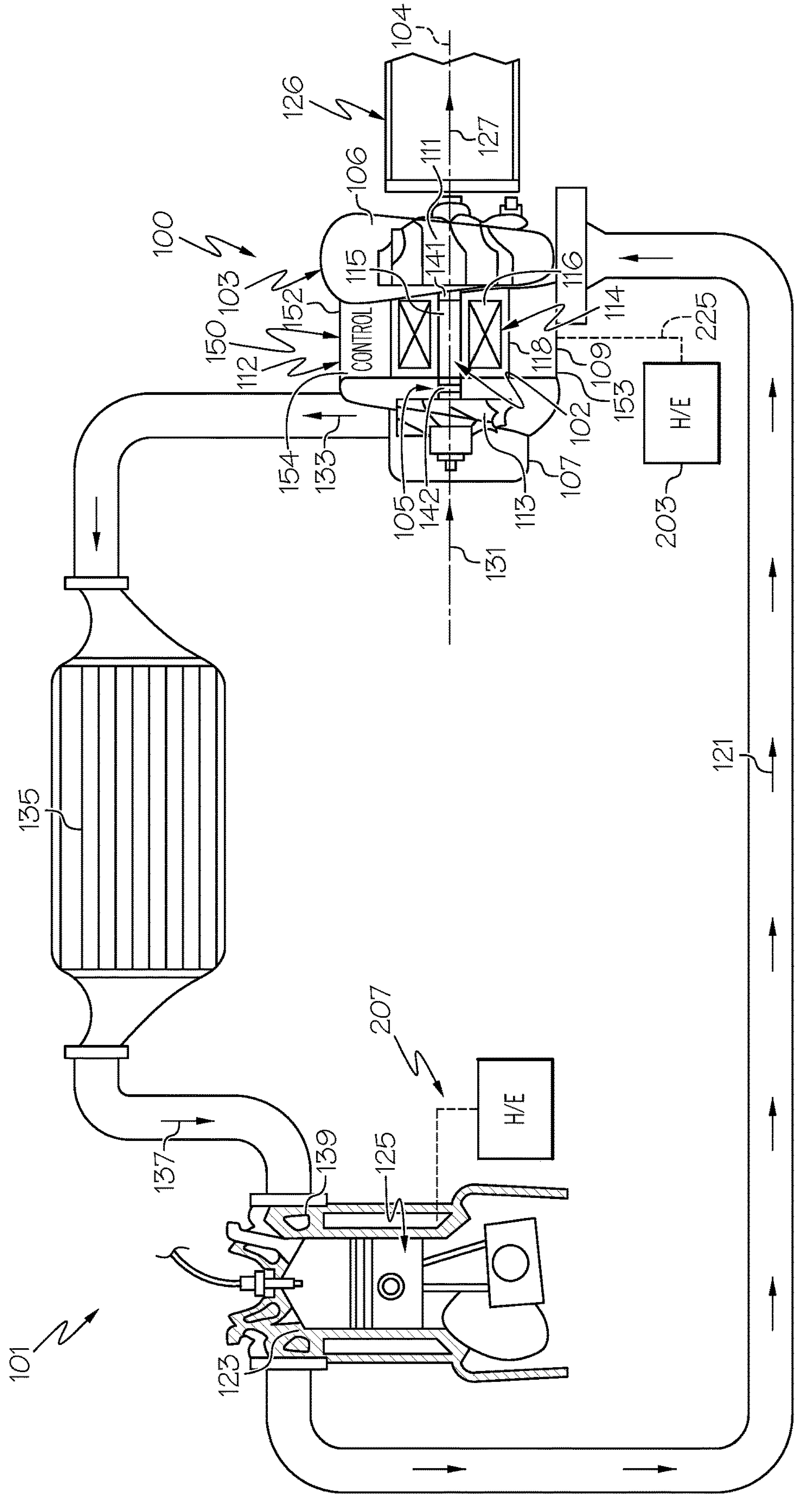
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FIG. 1

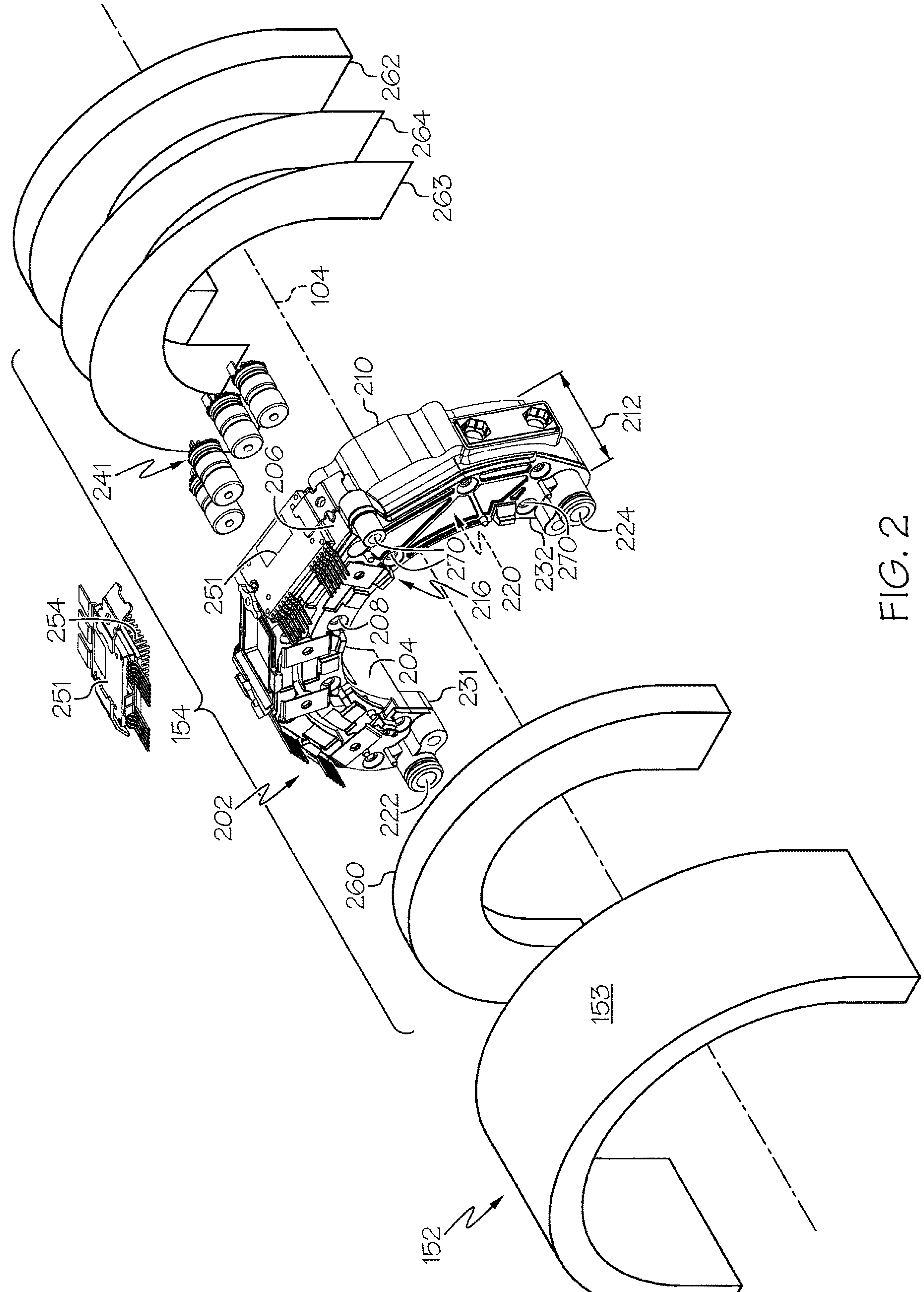
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FIG. 2

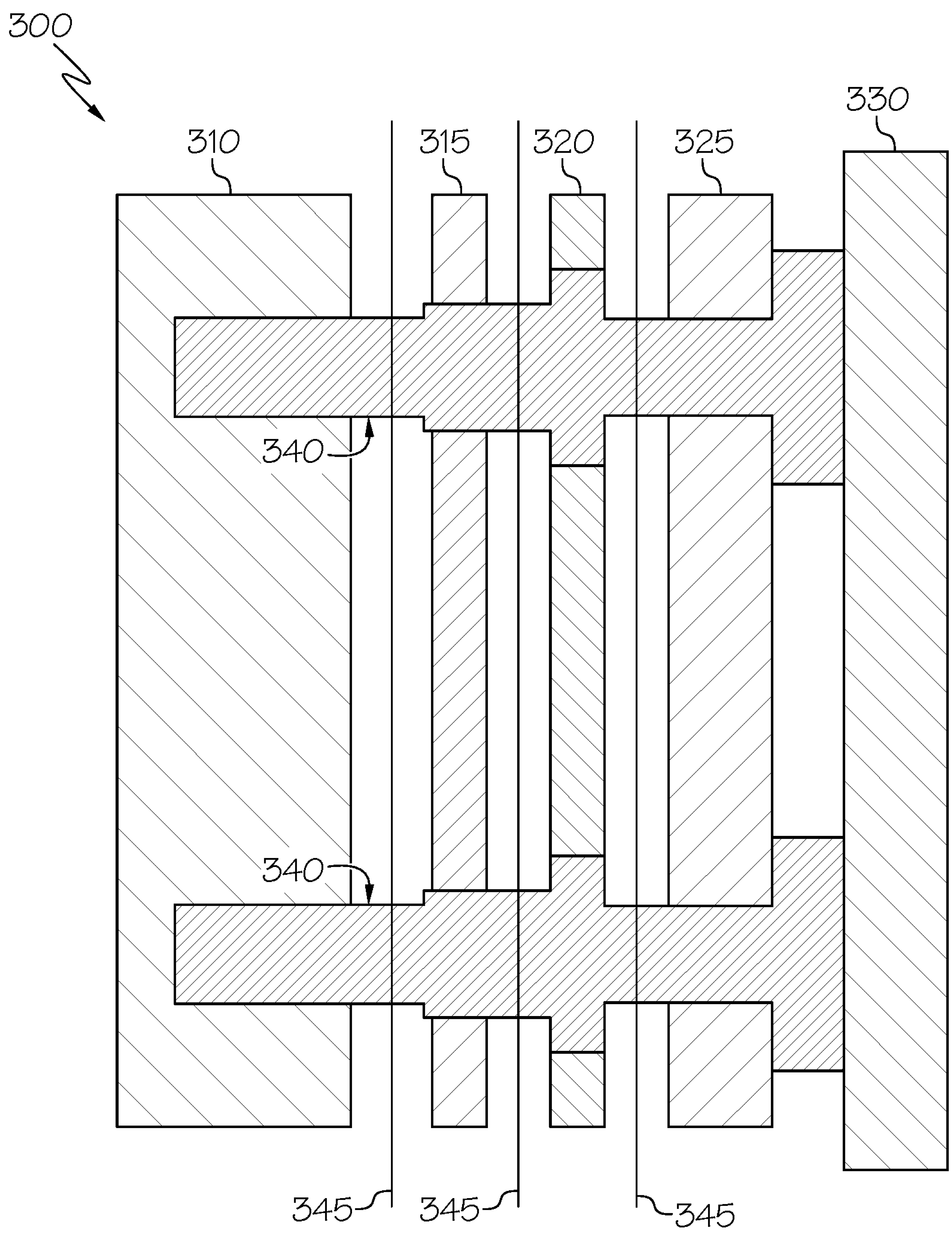
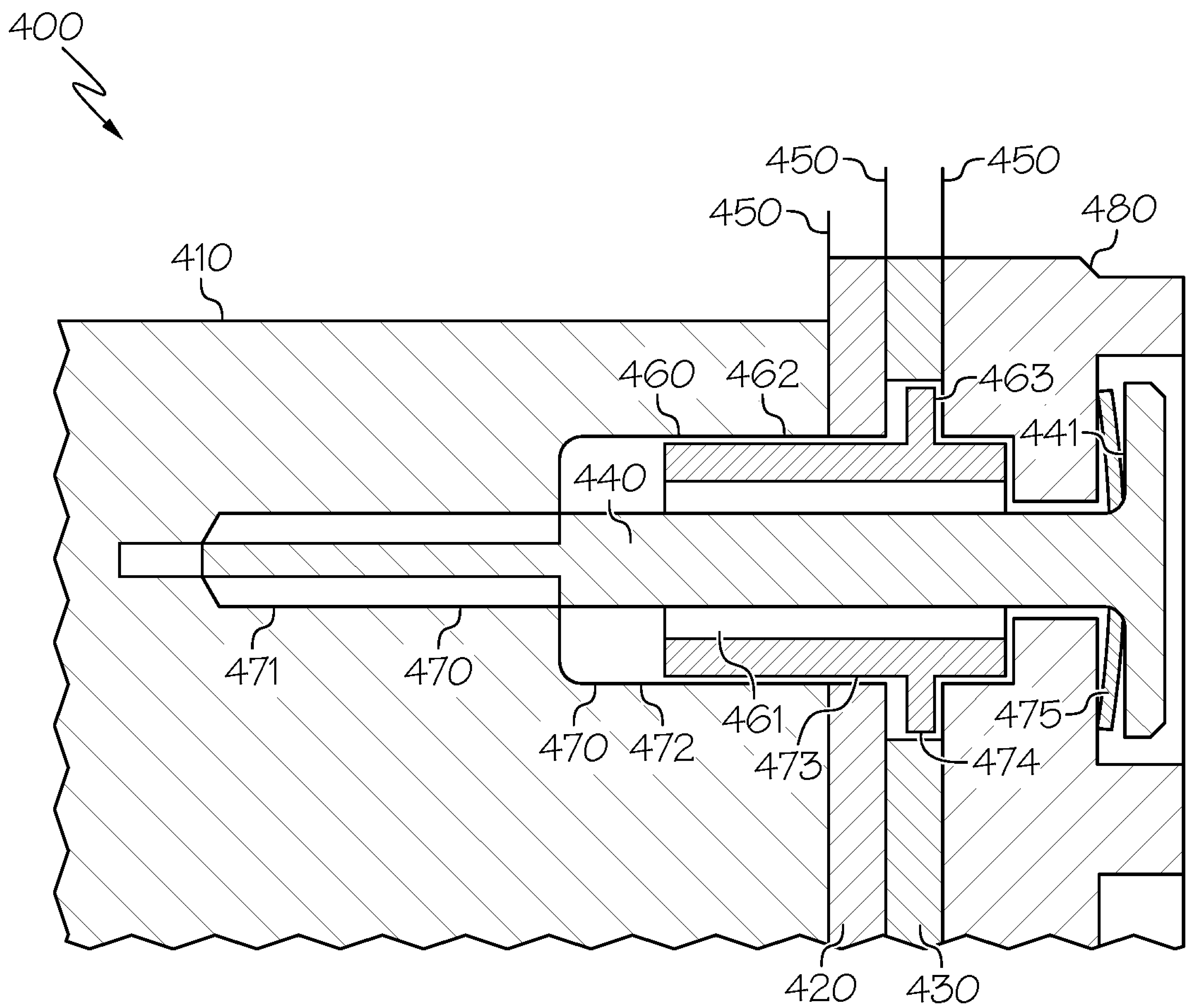


FIG. 3


400
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430

FIG. 4

INTEGRATED E-MACHINE CONTROLLER FOR TURBOMACHINE HAVING FASTENING ARRANGEMENT

TECHNICAL FIELD

The present disclosure generally relates to a turbomachine and, more particularly, relates to an integrated e-machine controller for a turbomachine having a fastening arrangement, for example, for fastening voltage supply bus bars therein.

BACKGROUND

Some turbomachines include an e-machine, such as an electric motor or generator. More specifically, some turbochargers, superchargers, or other fluid compression devices can include an electric motor that is operably coupled to the same shaft that supports a compressor wheel, turbine wheel, etc. The electric motor may drivingly rotate the shaft, for example, to assist a turbine stage of the device. In some embodiments, the e-machine may be configured as an electric generator, which converts mechanical energy of the rotating shaft into electric energy.

These devices may also include a controller that, for example, controls operation of the e-machine. More specifically, the control system may control the torque, speed, or other operating parameters of the e-machine and, as such, control operating parameters of the rotating group of the device.

However, conventional controllers of such fluid compression devices suffer from various deficiencies. These controllers can be heavy and/or bulky. Furthermore, the electronics included in the controller may generate significant heat, which can negatively affect operations. Similarly, the operating environment of the device can subject the electronics to high temperatures, vibrational loads, or other conditions that negatively affect operations. In addition, manufacture and assembly of conventional control systems can be difficult, time consuming, or otherwise inefficient.

Thus, it is desirable to provide an e-machine controller for a fluid compression device that is compact and that is retained in a robust manner. It is also desirable to thermally isolate the controller from high temperature vehicle components and to provide electrical isolation for current carrying parts from each other and electrical grounds. The current carrying parts may expand and contract during operation thereby requiring isolation gaps that compensate for the changes in physical sizing. It is also desirable to provide such a controller that provides manufacturing efficiencies. Other desirable features and characteristics of the present disclosure will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background discussion.

BRIEF SUMMARY

In one embodiment, a controller for an e-machine of a turbomachine having a rotating group that is supported for rotation about an axis is disclosed. The controller includes a support structure, a first bus bar that is elongate and that extends about the axis, a second bus bar that is elongate and that extends about the axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis, and a fastener arrangement that attaches the first bus bar and the second bus bar to the support structure.

In another embodiment, a method of manufacturing a controller for an e-machine of a turbomachine having a rotating group that is supported for rotation about an axis. The method of manufacturing including supporting a first bus bar that is elongate and that extends about the axis, operably coupling a second bus bar that is elongate and that extends about the axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis and engaging a fastener arrangement to attach the first bus bar and the second bus bar to a support structure coupled to the controller.

Moreover, a turbocharger including an integrated controller is disclosed having a rotating group that is supported for rotation about an axis. The turbocharger includes a support structure, a first bus bar that is elongate and that extends about a rotational axis of the turbocharger, wherein the first bus bar is electrically coupled to the integrated controller, a second bus bar that is elongate and that extends about the rotational axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis, wherein the first bus bar is electrically coupled to the integrated controller, and a fastener arrangement that attaches the first bus bar and the second bus bar to the support structure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will hereinafter be described in conjunction with the following drawing figures, wherein like numerals denote like elements, and wherein:

FIG. **1** is a schematic illustration of an engine system with a fluid compressor device that includes an integrated controller according to example embodiments of the present disclosure;

FIG. **2** is an exploded isometric view of the integrated controller according to exemplary embodiments of the present disclosure;

FIG. **3** is a cross sectional view of an electronics package of an integrated controller according to exemplary embodiments of the present disclosure; and

FIG. **4** is a cross sectional view of a fastener arrangement of an integrated controller according to exemplary embodiments of the present disclosure.

DETAILED DESCRIPTION

The following detailed description is merely exemplary in nature and is not intended to limit the present disclosure or the application and uses of the present disclosure. Furthermore, there is no intention to be bound by any theory presented in the preceding background or the following detailed description.

Broadly, example embodiments disclosed herein include an improved controller for a turbomachine. The controller may be integrated into, packaged among, and compactly arranged on the turbomachine for improved performance and for reducing the size and profile of the turbomachine. In some embodiments, the integrated controller may wrap, extend, span circumferentially, or otherwise be arranged about an axis of rotation defined by the rotating group of the turbomachine. The housing of the controller may be generally arcuate in some embodiments, and internal components (e.g., support structures, electronics components, and/or coolant system features) may be shaped, configured, assembled, and arranged about the axis to reduce the size of the turbomachine.

In addition, the turbomachine may be a compressor device, and the integrated controller may be arranged proximate the compressor section (e.g., proximate a compressor housing). Furthermore, the turbomachine may include a turbine section, and the compressor device may be disposed proximate thereto (e.g., proximate the turbine housing). The controller may, in some embodiments, be arranged compactly between a compressor section and a turbine section of the turbomachine. Furthermore, in some embodiments, the integrated controller may be wrapped or disposed about an e-machine (e.g., a motor) of the turbomachine. The controller may be configured for controlling the e-machine and their close proximity may increase operating efficiency.

The controller may, thus, be closely integrated and packaged within the turbomachine. The integrated controller may also include a fastener arrangement that robustly supports the electronics components. The fastener arrangement may electrically isolate different electrical components to ensure proper operations. The fastener arrangement may also provide improvements in manufacturing efficiency. Moreover, the fastener arrangement may attach heat-generating electrical components to a cooling plate or other structure, to a heat sink, to a coolant core, etc. such that the controller operates within acceptable operating temperatures. Thus, the electronic components may be tightly packed and may operate within extreme conditions, yet the controller may maintain operations over a long operating lifetime.

FIG. **1** is a schematic view of an example turbomachine, such as a turbocharger **100** that is incorporated within an engine system **101** and that includes one or more features of the present disclosure. It will be appreciated that the turbocharger **100** could be another turbomachine (e.g., a supercharger, a turbine-less compressor device, etc.) in additional embodiments of the present disclosure. Furthermore, the turbomachine of the present disclosure may be incorporated into a number of systems other than an engine system without departing from the scope of the present disclosure. For example, the turbomachine of the present disclosure may be incorporated within a fuel cell system for compressing air that is fed to a fuel cell stack, or the turbomachine may be incorporated within another system without departing from the scope of the present disclosure.

Generally, the turbocharger **100** may include a housing **103** and a rotating group **102**, which is supported within the housing **103** for rotation about an axis **104** by a bearing system **105**. The bearing system **105** may be of any suitable type, such as a roller-element bearing or an air bearing system.

As shown in the illustrated embodiment, the housing **103** may include a turbine housing **106**, a compressor housing **107**, and an intermediate housing **109**. The intermediate housing **109** may be disposed axially between the turbine and compressor housings **106**, **107**.

Additionally, the rotating group **102** may include a turbine wheel **111**, a compressor wheel **113**, and a shaft **115**. The turbine wheel **111** is located substantially within the turbine housing **106**. The compressor wheel **113** is located substantially within the compressor housing **107**. The shaft **115** extends along the axis of rotation **104**, through the intermediate housing **109**, to connect the turbine wheel **111** to the compressor wheel **113**. Accordingly, the turbine wheel **111** and the compressor wheel **113** may rotate together as a unit about the axis **104**.

The turbine housing **106** and the turbine wheel **111** cooperate to form a turbine stage (i.e., turbine section) configured to circumferentially receive a high-pressure and high-temperature exhaust gas stream **121** from an engine, specifically, from an exhaust manifold **123** of an internal combustion engine **125**. The turbine wheel **111** and, thus, the other components of the rotating group **102** are driven in rotation around the axis **104** by the high-pressure and high-temperature exhaust gas stream **121**, which becomes a lower-pressure and lower-temperature exhaust gas stream **127** that is released into a downstream exhaust pipe **126**.

The compressor housing **107** and compressor wheel **113** form a compressor stage (i.e., compressor section). The compressor wheel **113**, being driven in rotation by the exhaust-gas driven turbine wheel **111**, is configured to compress received input air **131** (e.g., ambient air, or already-pressurized air from a previous-stage in a multi-stage compressor) into a pressurized airstream **133** that is ejected circumferentially from the compressor housing **107**. The compressor housing **107** may have a shape (e.g., a volute shape or otherwise) configured to direct and pressurize the air blown from the compressor wheel **113**. Due to the compression process, the pressurized air stream is characterized by an increased temperature, over that of the input air **131**.

The pressurized airstream **133** may be channeled through an air cooler **135** (i.e., intercooler), such as a convectively cooled charge air cooler. The air cooler **135** may be configured to dissipate heat from the pressurized airstream **133**, increasing its density. The resulting cooled and pressurized output air stream **137** is channeled into an intake manifold **139** of the internal combustion engine **125**, or alternatively, into a subsequent-stage, in-series compressor.

Furthermore, the turbocharger **100** may include an e-machine stage **112**. The e-machine stage **112** may be cooperatively defined by the intermediate housing **109** and by an e-machine **114** housed therein. The shaft **115** may extend through the e-machine stage **112**, and the e-machine **114** may be operably coupled thereto. The e-machine **114** may be an electric motor, an electric generator, or a combination of both. Thus, the e-machine **114** may be configured as a motor to convert electrical energy to mechanical (rotational) energy of the shaft **115** for driving the rotating group **102**. Furthermore, the e-machine **114** may be configured as a generator to convert mechanical energy of the shaft **115** to electrical energy that is stored in a battery, etc. As stated, the e-machine **114** may be configured as a combination motor/generator, and the e-machine **114** may be configured to switch functionality between motor and generator modes in some embodiments as well.

For purposes of discussion, the e-machine **114** will be referred to as a motor **116**. The motor **116** may include a rotor member (e.g., a plurality of permanent magnets) that are supported on the shaft **115** so as to rotate with the rotating group **102**. The motor **116** may also include a stator member (e.g., a plurality of windings, etc.) that is housed and supported within the intermediate housing **109**. In some embodiments, the motor **116** may be disposed axially between a first bearing **141** and a second bearing **142** of the bearing system **105**. Also, the motor **116** may be housed by a motor housing **118** of the intermediate housing **109**. The motor housing **118** may be a thin-walled or shell-like housing that encases the stator member of the motor **116**. The motor housing **118** may also encircle the axis **104**, and the shaft **115** may extend therethrough.

Furthermore, the turbocharger **100** may include an integrated controller **150**. The integrated controller **150** may generally include a controller housing **152** and a number of internal components **154** (e.g., circuitry, electronic components, cooling components, support structures, etc.) housed within the controller housing **152**. The integrated controller **150** may control various functions. For example, the integrated controller **150** may control the motor **116** to thereby control certain parameters (torque, angular speed, START/STOP, acceleration, etc.) of the rotating group **102**. The integrated controller **150** may also be in communication with a battery, an electrical control unit (ECU), or other components of the respective vehicle in some embodiments. More specifically, the integrated controller **150** may receive DC power from a vehicle battery, and the integrated controller **150** may convert the power to AC power for controlling the motor **116**. In additional embodiments wherein the e-machine **114** is a combination motor/generator, the integrated controller **150** may operate to switch the e-machine **114** between its motor and generator functionality.

In some embodiments, the integrated controller **150** may be disposed axially between the compressor stage and the turbine stage of the turbocharger **100** with respect to the axis **104**. Thus, as illustrated, the integrated controller **150** may be disposed and may be integrated proximate the motor **116**. For example, as shown in the illustrated embodiment, the integrated controller **150** may be disposed on and may be arranged radially over the motor housing **118**. More specifically, the integrated controller **150** may extend and wrap about the axis **104** to cover over the motor **116** such that the motor **116** is disposed radially between the shaft **115** and the integrated controller **150**. The integrated controller **150** may also extend about the axis **104** in the circumferential direction and may cover over, overlap, and wrap over at least part of the motor housing **118**. In some embodiments, the integrated controller **150** may wrap between approximately forty-five degrees (45°) and three-hundred-sixty-five degrees (365°) about the axis **104**. For example, as shown in FIGS. **2**-**4**, the controller **150** wrap approximately one-hundred-eighty degrees (180°) about the axis **104**.

The controller housing **152** is shown schematically in FIG. **2**. As illustrated, the housing **152** may generally be arcuate so as to extend about the axis **104** and to conform generally to the rounded profile of the turbocharger **100**. The housing **152** may also be an outer shell-like member that is hollow and that encapsulates the internal components **154**. Electrical connectors may extend through the housing **152** for electrically connecting the internal components **154**. Furthermore, there may be openings for fluid couplings (e.g., couplings for fluid coolant). Additionally, the controller housing **152** may define part of the exterior of the turbocharger **100**. An outer surface **153** of the controller housing **152** may extend about the axis **104** and may face radially away from the axis **104**. The outer surface **153** may be at least partly smoothly contoured about the axis **102** as shown, or the outer surface **153** may include one or more flat panels that are arranged tangentially with respect to the axis **104** (e.g., a series such flat panels that are arranged about the axis **104**). The outer surface **153** may be disposed generally at the same radius as the neighboring compressor housing **107** and/or turbine housing **106** as shown in FIG. **1**. Accordingly, the overall size and profile of the turbocharger **100**, including the controller **150**, may be very compact.

The internal components **154** may be housed within the controller housing **152**. Also, at least some of the internal components **154** may extend arcuately, wrap about, and/or may be arranged about the axis **104** as will be discussed. Furthermore, as will be discussed, the internal components **154** may be stacked axially along the axis **104** in close proximity such that the controller **150** is very compact. As such, the integrated controller **150** may be compactly arranged and integrated with the turbine stage, the compressor stage, and/or other components of the turbocharger **100**. Also, internal components **154** of the controller **150** may be in close proximity to the motor **116** to provide certain advantages. For example, because of this close proximity, there may be reduced noise for more efficient control of the motor **116**.

Furthermore, the controller **150** may include a number of components that provide robust support and that provide efficient cooling. Thus, the turbocharger **100** may operate at extreme conditions due to elevated temperatures, mechanical loads, electrical loads, etc. Regardless, the controller **150** may be tightly integrated into the turbocharger **100** without compromising performance.

Referring now to FIG. **2**, the internal components **154** of the integrated controller **150** will be discussed in greater detail according to various embodiments. Generally, the integrated controller **150** from FIG. **1** may include a coolant core **202**. The coolant core **202** may be configured for supporting a number of electronic components, fastening structures, and other parts of the integrated controller **150**. The coolant core **202** may also define one or more coolant passages through which a fluid coolant flows for cooling the electronics components. The coolant core **202** may receive a flow of a coolant therethrough for cooling the integrated controller **150**. As illustrated in FIG. **2**, the coolant core extends at least partly over the motor **116** in a circumferential direction about the axis **104**.

The coolant core **202** may be elongate but curved and arcuate in shape and may extend in a tangential and/or circumferential direction about the axis **104**. In other words, the coolant core **202** may wrap at least partially about the axis **104** to fit about the motor **116** of the turbocharger **100**. Accordingly, the coolant core **202** may define an inner radial area **204** that faces the axis **104** and an outer radial area **206** that faces away from the axis **104**. Moreover, the coolant core **202** may include a first axial end **208** and a second axial end **210**, which face away in opposite axial directions. The first axial end **208** may face the compressor section of the turbocharger **100** in some embodiments and the second axial end **210** may face the turbine section in some embodiments. The coolant core **202** may also define an axial width **212**, which may be defined parallel to the axis **104** between the first and second axial ends **208**, **210**. Additionally, the coolant core **202** may be semi-circular and elongate so as to extend circumferentially between a first angular end **231** and a second angular end **232**, which are spaced apart angularly about the axis (e.g., approximately one-hundred-eighty degrees (180°) apart).

The coolant core **202** may be cooperatively defined by a plurality of parts, such as a reservoir body **214** and a cover plate **216**. Both the reservoir body **214** and the cover plate **216** may be made from strong and lightweight material with relatively high thermal conductivity characteristics (e.g., a metal, such as aluminum). In some embodiments, the reservoir body **214** and/or the cover plate **216** may be formed via a casting process (e.g., high pressure die casting).

The cover plate **216** may be relatively flat, may be arcuate (e.g., semi-circular), and may lie substantially normal to the axis **104**. Also, the cover plate **216** may define the first axial end **208** of the coolant core **202**. The reservoir body **214** may be a generally thin-walled and hollow body with an open side **209** that is covered over by the cover plate **216** and a second side **211** that defines the second axial end **210** of the coolant core **202**. The cover plate **216** may be fixed to the reservoir body **214** and sealed thereto with a gasket, seal, etc. One or more fasteners (e.g., bolts or other fasteners may extend axially through the cover plate **216** and the reservoir body **214** for attaching the same. The cover plate **216** and the reservoir body **214** may include one or more fastener holes **270** that receive a bolt or other fastener for attaching the first side electronics to the coolant core **202**. Accordingly, the cover plate **216** and the reservoir body **214** may cooperate to define a fluid passage **220** that extends through the coolant core **202**. In some embodiments, the fluid passage **220** may be elongate and may extend generally about the axis **104** from the first angular end **231** to the second angular end **232**.

The coolant core **202** may also include at least one fluid inlet **222** to the fluid passage **220** and at least one fluid outlet **224** from the fluid passage **220**. In some embodiments, for example, there may be a single, solitary inlet **222**. The inlet **222** may be disposed proximate the first angular end **231** and may include a round, cylindrical, and hollow connector **223** that projects along the axis **104** from the cover plate **216** away from the first axial end **208**. Also, in some embodiments, there may be a single, solitary outlet **224**. The outlet **224** may be disposed proximate the second angular end **232** and may include a round, cylindrical, and hollow connector **226** that projects along the axis **104** from the cover plate **216** away from the first axial end **208**.

The coolant core **202** may be fluidly connected to a coolant circuit **225**, which is illustrated schematically in FIG. **1**. The coolant circuit **225** may circulate any suitable fluid, such as a liquid coolant, between the fluid passage **220** and a heat exchanger **203** (FIG. **1**). More specifically, coolant may flow from the inlet **222**, through the fluid passage **220**, to the outlet **224**, thereby removing heat from the integrated controller **150**, and may continue to flow through the heat exchanger **203** to be cooled before flowing back to the inlet **222** of the coolant core **202**, and so on. Furthermore, as shown in FIG. **1**, the heat exchanger **203** may, in some embodiments, be separate and fluidly independent of an engine coolant system **207** that cools the engine **125**.

The second axial end **210** of the coolant core **202** may include one or more inner apertures **240**. The inner apertures **240** may include a plurality of pockets, recesses, receptacles, etc. that are open at the second side **211** of the reservoir body **214** and that are disposed proximate the inner radial area **204** of the core **202** in the radial direction. As shown, the inner apertures **240** may be generally cylindrical in some embodiments with circular profiles and with the longitudinal axis thereof arranged parallel to the axis **104**. There may be a plurality of inner apertures **240** arranged at different angular positions with respect to the axis **104** along the inner radial area **204** of the core **202**. The size and shape of the inner apertures **240** may correspond to certain ones of the internal components **154** of the integrated controller **150**. For example, the inner apertures **240** may be cylindrical, as shown, to receive and support inner electronics components, such as a series of capacitors **241** (FIG. **2**) of the controller **150**. The reservoir body **214** may define the apertures **240** with relatively thin walls **245** or other structures that separate the capacitors **241** within the apertures **240** from the coolant within the fluid passage **220**. Accordingly, the capacitors **241** may be effectively cooled by the coolant circuit **225**.

The second side **211** of the reservoir body **214** may include a second side aperture **246** that has an ovate profile and that is recessed in the axial direction into the reservoir body **214**. The second side aperture **246** may be arranged with the major axis of its ovate shape extending tangentially with respect to the axis **104**. Also, the minor axis may extend radially and may be large enough to extend over both the inner radial area **204** and the outer radial area **206** of the coolant core **202**. Furthermore, the second side aperture **246** may be shaped correspondingly to another electronics component, such as an inverter, capacitor, a battery, or another piece of control equipment.

Additionally, the outer radial area **206** of the coolant core **202** may extend about the axis **104** and may include one or more seats **219**. The seats **219** may be rectangular and may lie in a respective tangential plane with respect to the axis **104**. The seats **219** may be disposed and spaced apart at different angular positions with respect to the axis **104**. Furthermore, seats **219** may include a respective outer aperture **250** extending radially therethrough. In some embodiments, at least one outer aperture **250** may be a rectangular hole that is centered within the respective seat **219** and that passes through the reservoir body **214** to the fluid passage **220** therein. These outer apertures **250** may be sized and configured to receive an outer electronics component **251** (FIG. **2**), such as a substantially-flat and rectangular transistor, circuit component, switch component, MOSFET transistor, etc. The electronics component **251** may be partially received in a respective outer aperture **250** and may be supported and mounted on a respective seat **219** so as to cover over the respective outer aperture **250**. There may be a gasket or other sealing member that seals the electronics component **251** to the seat **219**. Also, the electronics component **251** may include one or more thermally-conductive projections **254** (FIG. **2**), such as an array of fins, rails, posts, pins, etc.) that project from an underside thereof to extend into the fluid passage **220**. Accordingly, coolant within the coolant circuit **225** may flow across the projections **254** to provide highly effective cooling to the electronics component **251**.

Additionally, the first axial end **208** defined substantially by the cover plate **216** may provide one or more surfaces for mounting and supporting a first side electronics package **260**. The first side electronics package **260** is represented schematically in FIG. **2** as a semi-circular body that corresponds generally to the shape of the coolant core **202**, and it will be appreciated that the first side electronics package **260** may comprise a plurality of electronics components, such as one or more conductive bus bars, circuit board assemblies, etc. There may also be support structures, such as brackets, plates, etc. for supporting the electronics package **260**. Furthermore, there may be a fastener arrangement for attaching the first side electronics package **260** to the first axial end **208** of the coolant core **202**. The fastener arrangement may include support structures with threaded cavities, bolts, washers, bushings, and the like. The first side electronics package **260** may be layered on the first axial end **208** such that both extend arcuately about the axis **104**. The first side electronics package **260** may be attached to the first axial end **208** in any suitable fashion, such as fasteners. Accordingly, the first side electronics package **260** may be in close proximity with at least one surface of the package **260** layered on and abutting an opposing surface of the coolant core **202** such that the coolant core **202** may absorb heat therefrom with high efficiency and effectiveness.

Likewise, the second axial end **210** of the coolant core **202** may provide one or more surfaces for mounting and supporting a second side electronics package **262**. Like the first side electronics package **260**, the second side electronics package **262** is represented schematically, however, it will be appreciated that the package **262** may include a number of electronic and/or mechanically supportive/fastening parts. The second side electronics package **262** may be arcuate and may extend partly about the axis **104**. The second side electronics package **262** may be layered on the second axial end **210** such that both extend arcuately about the axis **104**. The second side electronics package **262** may be attached to the second axial end **210** in any suitable fashion. Moreover, the second side electronics package **262** may be in close proximity to the coolant core **202** with at least one surface of the package **262** layered on and abutting an opposing surface of the coolant core **202** for efficient and effective cooling. In at least one exemplary embodiment, a first bus bar **263** and a second bus bar **264** may be mounted between the second side electronics package **262** and the second axial end **210**. The first bus bar **263** and the second bus bar **264** may be used to conduct electrical current to the second side electronics package **262**, the outer electronics component **251** and/or the first side electronics package **260**. The conducted electrical current may be direct current or alternating current.

The fluid passage **220** for the coolant within the coolant core **202** may be defined between the inner surfaces of the reservoir body **214**, the inner face of the cover plate **216**, and the inner faces of the outer electronics components **251**. The fluid passage **220** may also extend arcuately about the axis **104**, from the inlet **222** to the outlet **224**. Coolant may enter via the inlet **222**, flow generally from the first angular end **231** to the second angular end **232** and exit via the outlet **224**. Accordingly, the coolant may flow in close proximity and across the core-facing surfaces of the outer electronics components **251**, the capacitors **241**, the first side electronics package **260**, and the second side electronics package **262**.

Accordingly, in some embodiments, the coolant core **202** may be substantially surrounded by heat-producing electronics components. The coolant core **202** may be thermally coupled to these components due to the close proximity and, in some areas, due to abutting contact therebetween. Some interfaces (e.g., at the projections **254**) may provide direct fluid contact with the coolant. As shown in FIG. **2**, the coolant core **202** may be thermally coupled to the electronics components on the inner radial area **204**, the outer radial area **206**, the first axial end **208** and the second axial end **210**. The fluid passage **220** may be defined radially between the inner radial area **204** and the outer radial area **206** to receive heat from both the inner electronics components (e.g., the capacitors **241**) and the outer electronics components **251**. Moreover, the fluid passage **220** may be defined axially between the first and second axial ends **208**, **210** to receive heat from both the first and second side electronics packages **260**, **262**.

Furthermore, the controller **150** may be integrated and packaged among the turbine section, the motor **116**, and/or the compressor section, any of which may operate at elevated temperatures. The coolant core **202** and the coolant circuit **225** may provide cooling to these surrounding components as well. Thus, it will be appreciated that the controller **150** may be packaged compactly and that there may be several features that generate heat during operation; however, the coolant core **202**, the coolant circuit **225**, and other features discussed above may provide effective and efficient cooling.

Moreover, the controller **150** may be robustly supported on the turbocharger **100**. The coolant core **202** may provide mechanical support while also providing compact packaging for the controller **150**. Also, the part count may be relatively low and the controller **150** may be manufactured and assembled in an efficient manner.

Turning now to FIG. **3**, an exemplary cross-sectional view of an electronics package **300** of an integrated controller **150** is shown. The exemplary electronics package **300** may be generally representative of one or more of the first side electronics package **260** or the second side electronics package **262** as described in accordance with FIG. **2**. The exemplary electronics package **300** may include a support structure **310**, a first bus bar **315**, a second bus bar **320**, a backing plate **325**, a printed circuit board **330**, at least one fastener arrangement **340**, and a plurality of non-conductive sheets **345**. The exemplary fastener arrangements **340** may include a bolt, a bushing, and a spring washer for rigidly affixing the first bus bar **315**, the second bus bar **320**, and the backing plate **325** to the support structure **310**.

The support structure **310** may be representative of the coolant core **202** of FIG. **2** in some embodiments; however, it will be appreciated that the support structure **310** may be another part of the integrated controller **150** or another engine component, turbomachine, integrated controller, or other vehicle component. The support structure may form a rigid structure for providing support to the electronic components of the exemplary electronics package **300**. Ideally, the support structure **310** may be integrated into the turbomachine **100** and the controller **150**.

The first bus bar **315** and the second bus bar **320** in this exemplary configuration may be used to conduct voltages used by the electronics package and/or the turbomachine and integrated controller. The first bus bar **315** may carry a first electrical voltage such as a direct current (DC) voltage at a first DC voltage level or an alternating current (AC) signal with a first AC voltage and a first phase. Likewise, the second bus bar **320** may carry a second electrical voltage such as a direct current (DC) voltage at a second DC voltage level or an alternating current (AC) signal with a second AC voltage and a second phase. The support structure **310**, the first bus bar **315**, the second bus bar **320** and the backing plate **325** may be electrically isolated from each other by the plurality of non-conductive sheets **345**. In some exemplary embodiments, the non-conductive sheets are separate from the other components and are fixed in place during assembly of the electronics package **300**. In other embodiments, the non-conductive sheets **345** may be formed by coating the various components, such as the first bus bar **315** and the second bus bar **320** with a film or layer of non-conductive material such as polyamide or the like.

The backing plate **325** may be used to support and distribute a uniform clamping force on the first bus bar **315** and second bus bar **320** when the fastener arrangements **340** are attached to the support structure **310**. The fastener arrangements **340** may have a threaded portion for engaging a threaded cavity in the support structure **310**. The fastener arrangements **340** may further have smooth portions for rotating freely within a bushing or a non-threaded cavity within the support structure **310**. The fastener arrangements **340** may further have portions of differing diameters to secure different components at different layers of the electronics package.

The printed circuit board **330** may be further affixed to the electronics package **300** for conditioning or controlling the voltages on the first bus bar **315** and the second bus bar **320** as well as providing control information, sensors and the like to the integrated controller **150** of the turbomachine **100**. The printed circuit board **330** may be affixed within the electronics package using the fastener arrangements **340** or may be affixed by other means independent of the fastener arrangements **340**. The printed circuit board **330** may be affixed with other fasteners, such as screws, or bossed to avoid any possible distortion resulting from the holding force of the fastener arrangements **340**

Turning now to FIG. **4**, additional embodiments of a cross sectional view of a fastener assembly **400** of an integrated controller according to exemplary embodiments of the present disclosure is represented. The exemplary fastener assembly **400** may form a portion of the controller **150** for the motor **116** of the turbomachine **100** of FIG. **1**, for example.

In one or more exemplary embodiments, the support structure **410** may form a portion of the coolant core **202** of the integrated controller **150** or the like. The support structure **410** will have an electrical potential that is different from the electrical potential of the first bus bar **420** and the second bus bar **430**. The support structure **410** may be configured to provide physical support and may be electrically and/or thermally isolated from the first bus bar **420** and the second bus bar **430**.

The first bus bar **420** may be configured for suppling a first voltage to the integrated controller **150** and the second bus bar **430** for supplying a second voltage to the integrated controller **150**. In some embodiments, the first voltage and the second voltage are different direct current voltages wherein the first voltage does not equal the second voltage. Alternatively, the first bus bar **420** and the second bus bar **430** may conduct alternating current (AC) voltages wherein the voltage carried by the first bus bar **420** is out of phase with, or has a different phase than, the voltage carried by the second bus bar **430**. In some embodiments, the first bus bar **420** and the second bus bar **430** may be separated by one or more non-conductive sheets **450**. These non-conductive sheets **450** may be formed separately from the first bus bar **420** and the second bus bar **430**, or the first bus bar **420** and the second bus bar **430** may be coated with a non-conductive material. For example, the non-conductive material may be a dielectric material or other electrically insulating material. In addition, the non-conductive sheets **450** may further include thermal insulating properties. In some exemplary embodiments, the non-conductive sheets **450** may be a polyamide material that is between approximately 0.001 to 0.002 inches thick.

In exemplary embodiments, the first bus bar **420** may be elongated and may extend about the axis **104**. Likewise, the second bus bar **430** may be elongate and may extend about the axis **104**. Also, the second bus bar may be stacked on the first bus bar in an axial direction with respect to the axis **104**. The first bus bar **420** and the second bus bar **430** may be affixed to the support structure **410** by a fastener arrangement **340** of FIG. **3**.

In some exemplary embodiments, the fastener arrangement **340** of FIG. **3** may include a sleeve bushing **460**, a fastener **440**, and a resilient washer **475**. In some embodiments, the fastener **440** may be a partially threaded fastener, such as a bolt or the like. The sleeve bushing **460** may be a tubular structure. The sleeve bushing **460** may have an inner surface **461** having an inner radius, an outer surface **462** having an outer radius, and a flange **463** affixed to the outer surface **462** of the sleeve bushing **460**. The flange **463** may be circular in some embodiments and may define a flange radius. In some embodiments, the sleeve bushing **460** may be formed of a non-conducting material, such as dielectric material, ceramic, etc., or the bushing **460** may be formed from a conductive material coated with an electrically insulating material.

In some embodiments, the support structure **410** may include a receiver cavity **470** for receiving the fastener **440**. The receiver cavity **470** may include a cavity threaded portion **471** with a radius corresponding to a radius of the fastener **440** for threaded attachment therebetween. The receiver cavity **470** may also include a non-threaded portion **472** corresponding to an outer radius of the sleeve bushing **460** for a clearance fit there between. Thus, the fastener **440** may threadably attach to the threaded portion **471** of the receiver cavity **470** with the bushing **460** received in the non-threaded portion **472** of the receiver cavity **471**.

The first bus bar **420** may include a first aperture **473** having a first aperture radius corresponding to the outer radius of the sleeve bushing **460** such that there is a clearance fit there between. The second bus bar **430** may include a second aperture **474** having a second radius corresponding to the flange radius of the flange **463** of the sleeve bushing **460** such that there is a clearance fit therebetween. Also, the second radius of the second aperture **474** may be greater than the first radius of the first aperture. In some embodiments, the first bus bar **420** may be applied to the support structure **410** such that the first aperture **473** aligns with the receiver cavity **470** and the second bus bar **430** may be layered upon and applied to an outer surface of the first bus bar such that the second aperture **474** aligns with the first circular aperture **473** and the receiver cavity **470**. The sleeve bushing **460** may be located such that a first portion of the outer surface **462** is located and received within the non-threaded portion **472** of the receiver cavity **470**, a second portion of the outer surface **472** is located and received within the first aperture **473** of the first bus bar **420**, and the flange **463** is located and received within the second aperture **474** of the second bus bar **430**. In this embodiment, the fastener **340** is then located within the inner surface **461** of the sleeve bushing **460**, having a fastener threaded portion engaged with the cavity threaded portion **471** and fastener head **441** received in a recess of the backing plate **480**.

The assembly may optionally include a backing plate **480** that is also secured by the fastener **440** in order to distribute loads over the first bus bar **420**, the second bus bar **430** and the support structure **410**. The backing plate **480** may be a relatively flat plate that is elongate and that extends at least partly about the axis **104**. The backing plate **480** may be referred to as a backing plate in some embodiments. This backing plate **480** may be fabricated, machined from, or molded from, aluminum and may be stiff and strong to resist deformation as a result of force applied by the fasteners **440**.

When fastening the first bus bar **420** and the second bus bar **430** to the support structure **410**, it is desirable to provide a sufficient creep distance between components carrying an electrical charge and grounded components. During assembly, a flat wide metal washer (not shown) between the spring washer and plastic bushing may be used to increase area which the clamp force is applied to the plastic bushing. In addition, suitable metal feature may be formed in the support structure **480** to increase the clamping force area of the resilient washer **475**. In order to achieve a safe creep distance around the fastener **440** while limiting the risk of the bus bars **420**, **430** contacting each other or other metal structures and short circuiting, it is advantageous that the first diameter of the first circular aperture **473**, the second circular aperture **474**, and the second portion of the outer surface **473** of the receiver cavity **470** have differing radii such that the edges of the apertures do not align during fastening to allow for a safe creep distance around the fastener **440**. In an alternate embodiment, the support structure **410** and/or the backing plate **480** may be counterbored (not shown) and the adjacent non-conductive sheets **450** may be extended to overhang the counterbore. The larger diameter of the counterbore enlarges the safe creep distance around the fastener **440**.

The fastener arrangement **400** may further include a resilient member, such as a resilient washer **475**, situated between a portion of the fastener **440** and the backing plate **480**. The resilient washer **475** may be a spring washer, a Belleville washer, etc. The resilient washer **475** may be annular and may be received on the fastener **440**, disposed axially between the head **441** of the fastener **440** and the backing plate **480**. The resilient washer **475** may resiliently flex from a neutral position to a flexed position as the fastener **440** is attached to support structure **410**. In addition, an intermediate metal surface, such as a flat washer, or flat feature of the backing plate **480**, may be used to spread the load out across the plastic bushing from the resilient washer **475**.

In some embodiments, the sleeve bushing **460** may be malleable or flexible and may be distorted such that the outer radius is increased in response to the pressure from the fastener assembly. This distortion may have the effect of providing pressure between the distorted sleeve bushing **460** and the inside of the receiver cavity, the inner surface of the first aperture **473** and/or the inner surface of the second aperture **474**. This distortion may then have the beneficial effect of further securing the first bus bar **420** and the second bus bar **430** to the support structure **410**. Accordingly, the sleeve bushing **460** may include a resilient member that is resiliently flexible between a neutral position and a flexed position, and wherein the resilient member is in the flexed position when the fastener arrangement **400** attaches the first bus bar **420** and the second bus bar **430** to the support structure **410**.

The fastener arrangement **400** may robustly support the components of the integrated controller **150** and may electrically isolate components from each other as needed. Also, the fastener arrangement **400** may provide compact packaging for the integrated controller **150**. The fastener arrangement **400** may facilitate increased manufacturing efficiency and ease of assembly. The fastener arrangement **400** addresses the need to secure the first bus bar **420** and the second bus bar **430** to the support structure **410** in a manner that facilitates thermal conduction from the bus bars **420**, **430** to the support structure **410** which may be formed from a portion of the coolant core **202**. Specifically, for example, heat of the second bus bar **430** may transfer conductively to the first bus bar **420**, and/or the heat of the first bus bar **420** may transfer conductively to the support structure **410**, which may provide cooling via a fluid coolant flowing therethrough. The durable sleeve bushing **460** may provide mechanical stability and fixation while providing good electrical isolation. The sleeve bushing **460** may be fabricated from a glass and mineral filled plastic or a ceramic composite to allow for high pressure clamping by the fastener **440** in a high temperature environment. The sleeve bushing **460** facilitate assembly by electrically isolating the fastener **440** and fastener head **441** from the electrically active first bus bar **420** and second bus bar **430**. The design of the sleeve bushing **460** and the material chosen for the sleeve bushing **460** helps overcome harsh thermal and vibration environments (e.g., those of a vehicle-engine-mounted environment) and is capable of being used for high voltage applications as well as allowing the collocation of multiple busbars instead of just a single busbar.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or exemplary embodiments are only examples, and are not intended to limit the scope, applicability, or configuration of the present disclosure in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing an exemplary embodiment of the present disclosure. It is understood that various changes may be made in the function and arrangement of elements described in an exemplary embodiment without departing from the scope of the present disclosure as set forth in the appended claims.

What is claimed is:

1. A controller for an e-machine of a turbomachine having a rotating group that is supported for rotation about an axis comprising:

- a support structure;
- a first bus bar that is elongate and that extends about the axis;
- a second bus bar that is elongate and that extends about the axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis;
- a dielectric layer that electrically isolates the first bus bar from the second bus bar; and
- a fastener arrangement that attaches the first bus bar and the second bus bar to the support structure.

2. The controller of claim **1** wherein the fastener arrangement further includes a fastener and a sleeve bushing, the fastener extending through the first bus bar and the second bus bar and fixed to the support structure, the sleeve bushing receiving the fastener, the sleeve bushing received in the first bus bar and in the second bus bar.

3. The controller of claim **2** wherein the sleeve bushing is formed from a dielectric material.

4. The controller of claim **2** wherein the sleeve bushing is deformable such that an outer radius of the sleeve bushing is increased in response to attachment of the fastener to the support structure.

5. The controller of claim **2** wherein the support structure includes a receiver cavity, the receiver cavity having a cavity threaded portion that threadably attaches to the fastener, and wherein the receiver cavity has a non-threaded portion of the fastener corresponding to an outer radius of the sleeve bushing with a clearance fit therebetween.

6. The controller of claim **2**, wherein the first bus bar includes a first aperture having a first aperture radius and the second bus bar includes a second aperture having a second radius, and wherein the second radius is different than the first radius.

7. The controller of claim **2**, wherein the fastener arrangement includes a resilient washer disposed between a fastener head of the fastener and at least one of the first bus bar and the second bus bar.

8. The controller of claim **2**, further comprising a backing plate;

- wherein the support structure includes a receiver cavity that receives the fastener;
- wherein the first bus bar includes a first aperture that is aligned with the receiver cavity, the first aperture receiving the sleeve bushing;
- wherein the second bus bar includes a second aperture that is aligned with the first aperture and the receiver cavity, the second aperture receiving the sleeve bushing;
- wherein the sleeve bushing is received within the receiver cavity; and
- wherein the fastener is received in the sleeve bushing, the fastener including a fastener head, the backing plate disposed between the fastener head and the sleeve bushing.

9. The controller of claim **1** wherein the first bus bar is a first electrical bus bar having a first voltage and the second bus bar is a second electrical bus bar having a second voltage.

10. The controller of claim **1** wherein the support structure is a cooled structure and configured to receive heat from the first bus bar and the second bus bar.

11. A turbocharger having an integrated controller comprising:

a support structure;

a first bus bar that is elongate and that extends about a rotational axis of the turbocharger, wherein the first bus bar is electrically coupled to the integrated controller;

a second bus bar that is elongate and that extends about the rotational axis, the second bus bar stacked on the first bus bar in an axial direction with respect to the axis, wherein the first bus bar is electrically coupled to the integrated controller;

a dielectric layer that electrically isolates the first bus bar from the second bus bar; and

a fastener arrangement that attaches the first bus bar and the second bus bar to the support structure including:

a fastener; and

a sleeve bushing, the fastener extending through the first bus bar and the second bus bar and fixed to the support structure, the sleeve bushing receiving the fastener, the sleeve bushing received in the first bus bar and in the second bus bar.

12. The turbocharger having an integrated controller of claim **11** wherein the sleeve bushing is made of a dielectric material;

further comprising a backing plate;

wherein the sleeve bushing has an outer flange;

wherein the outer flange is received within the second bus bar;

wherein the first bus bar, the second bus bar, and the backing plate are stacked and axially disposed between a head of the fastener and the support structure; and

further comprising a resilient washer disposed between the head of the fastener and the backing plate.

13. A method of manufacturing a controller for an e-machine of a turbomachine having a rotating group that is supported for rotation about an axis comprising:

providing a support structure;

stacking a first bus bar and a second bus bar in an axial direction with respect to the axis in a stack, the first bus bar and the second bus bar extending about the axis;

applying a dielectric layer between the first bus bar and the second bus bar that electrically isolates the first bus bar from the second bus bar; and

attaching the stack to the support structure with a fastener arrangement.

14. The method of manufacturing of claim **13** wherein the fastener arrangement includes a fastener and a sleeve bushing, the fastener extending through the first bus bar and the second bus bar and fixed to the support structure, the sleeve bushing receiving the fastener, the sleeve bushing received in the first bus bar and in the second bus bar.

15. The method of manufacturing of claim **14** wherein the sleeve bushing is formed from a dielectric material.

16. The method of manufacturing of claim **14** further comprising:

extending the fastener through a backing plate, through the second bus bar, and through the first bus bar;

locating the sleeve bushing partly within the support structure, locating the sleeve bushing within the first bus bar, and locating a bushing flange of the sleeve bushing within the second bus bar and axially between the first bus bar and the backing plate; and

engaging the fastener to the support structure such that the first bus bar, the second bus bar, and the backing plate are compressed between the support structure and a fastener head of the fastener.

17. The method of manufacturing of claim **16** wherein the fastener arrangement further includes a resilient washer that is disposed between the fastener head and at least one of the first busbar and the second busbar.

18. The method of manufacturing of claim **13** wherein the support structure is a cooled structure and configured to receive heat from the first bus bar and the second bus bar.

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